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# Small Wind Turbine Applications: Current Practice in Colorado

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# Small Wind Turbine Applications: Current Practice in Colorado

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Numerous small wind turbines are being used by homeowners in Colorado. Some of these installations are quite recent while others date back to the federal tax-credit era of the early 1980s. Through visits with small wind turbine owners in Colorado, I have developed case studies of six small wind energy applications focusing on the wind turbine technology, wind turbine siting, the power systems and electric loads, regulatory issues, and motivations about wind energy. These case studies offer a glimpse into the current state-of-the-art of small-scale wind energy and provide some insight into issues affecting development of a wider market.

## Case Study 1

This is a family of three living on 120 acres (.5 km^2) in rural Douglas County, Colorado. Their home is located near the Palmer Divide, an elevated region between Denver and Colorado Springs. The local topography provides unusually energetic winds for eastern Colorado.

Their off-grid home is powered by a hybrid wind and photovoltaic system with diesel backup:

- World Power Technology (WPT) Whisper 4500 wind turbine, 4.5 kW,
  14.7 ft (4.5 m) diameter rotor, battery-charging
- WPT Whisper H900 wind turbine, 900 W, 7 ft (2.1 m) diameter rotor, battery-charging
- Solec PV panels, 1.44 kW
- 48 VDC battery bank.
- Stacked pair of Trace SW4048 inverters, 240 VAC, 1 phase, 8 kW total
- Diesel genset, 12 kW

The home has electric space heat and hot water. Excess wind power has been adequate to serve these thermal loads. Only recently, a propane tank was added for backup. The major appliances in the home—refrigerator, washer, and drier—are European-made energy efficient models. In the near future, they will add two more WPT wind turbines, 900 W and 1000 W, to expand the system.

The 4500 wind turbine is installed on the top of a mesa about 300 ft (90 m) above the house. This location has higher wind speeds than at the house, but also turbulence created as the wind flows up the slope of the mesa. The tower height, formerly 42 ft (13 m), has been increased to 63 ft (19 m) in an attempt to get the wind turbine into smoother air. Originally a three-bladed unit, the 4500 wind turbine has been converted to two blades under a recall by the manufacturer. In its short life, the turbine has failed and subsequently been serviced under warranty several times. (This model has been taken off the market by WPT.)

The H900 is located on the mesa slope within 100 ft (30 m) of the house. (See Figure 1.) The wind resource here is still quite good and turbulence is reduced. This turbine is less than one year old and has performed flawlessly to date. It is audible inside the home when it is furling in high winds, > 30 mph (13.4 m/s). It was described as sounding “like the propeller of a small airplane.” At lower wind speeds, it is very quiet.

About four years ago, this homeowner declined to interconnect to the local electric co-op for a $12,000 fee. He is driven to be energy independent with renewable energy. His home power system is his hobby—he loves to tinker and experiment. He did all the design and installation himself. He did not obtain any permits from the county for the wind turbines. He claims to be allowed construction for agricultural purposes without permits. He carries no insurance on either the power system or the home.

*Figure 1. Whisper 900 wind turbine on hillside above Douglas County home, Case Study 1.*

## Case Study 2

The next case study is a family of four in a rural residential area of Boulder County. (See Figure 2.) The location is problematic for siting a wind turbine. The exposure to north and west winds is quite good. But to the south, there is a row of cottonwood trees with a steep hill right behind rising to 130 ft (40 m) above the homesite. South winds, common in summer, will be severely restricted at this location.

The home is on-grid with net metering and boasts a substantial renewable energy system:

- WPT 3000 wind turbine, 3 kW, 14.7 ft (4.5 m) diameter rotor, battery-charging
- BP Solar model 590 PV panels, 8.6 kW
- 54 VDC battery bank.
- Stacked pair of Trace SW5548 inverters, 240 VAC, 1 phase, 11 kW total

This system has generated net excess energy every month it has operated. The home itself is super-insulated, passive-solar, and all electric. Major electric appliances include electric drier, stove, and oven. Space heat and hot water are electric through a ground-source heat pump. The family also has an electric car that consumes about 200 kWh/month. Only the gas fireplace, supplied from a 5-gal (19 l) propane tank, is fuel-fired. Total power consumption is about 1000 kWh/mo.

The wind turbine was recently added to the previously PV-only power system for the purpose of supplementing the reduced PV output during the winter months. It was installed under a building permit that limits its height measured at the top of the rotor to just 30 ft (9 m). Unfortunately, this site begs for a taller tower. Intending to double the height to 60 ft (18 m), the owner has initiated a review process with the county that includes a $400 fee, a written application, notification of neighbors within 1500 ft (460 m)—90 households—and 17 cognizant agencies all leading to a public hearing before the county commissioners. This process is still underway.

*Figure 2. Whisper 3000 wind turbine adjacent to passive-solar home with PV panels on roof, Case Study 2.*

Another regulatory obstacle has been encountered as well. The electrical inspector has not approved the original installation citing lack of a UL label on the wind turbine controller. Standard homeowners insurance is carried on the house with no added riders for the wind turbine.

This household was the very first to go on-line under Public Service Company of Colorado's net metering pilot program. However, their intention is to go off-grid entirely in the future. They are motivated by a commitment to renewable energy as well as concerns about global warming. Their approach is an unusual combination of an all-electric home; a renewable power system; passive-solar, super-insulated building design; and the choice to not compromise their lifestyle.

## Renewable Zealots

These first two case studies I refer to as "Renewable Zealots." They are highly committed, do-it-yourself homeowners, smart, informed, and driven. Their goal is off-grid energy independence with renewable energy. They are not using strict economic least-cost rationale in their decision-making. Very simply, it's not about the money. They buy what they can afford while looking for good value in their purchases. Also, they are not dissuaded by zoning or permitting hurdles. They either persevere or disregard them entirely.

## Case Study 3

This case study is of a weekend cabin in South Park, a high mountain valley in central Colorado. (See Figure 3.) The cabin is off-grid and located at an elevation of 9660 ft (2945 m). The low air density at this elevation will reduce the power in the wind by about 26% compared to the same wind speeds at sea level. (This compares to a reduction of about 16% for the other case studies, all in the Denver area around 5500 ft [1676 m] elevation.) Winds as high as 110 mph (49 m/s) have been measured at this site.

The electric power system consists of the following:

- Southwest Windpower 503 wind turbine, 500 W, 5 ft (1.5 m) diameter rotor, battery-charging
- PV panels, 188 W
- 24 VDC battery bank
- Heart inverter, 2.5 kW, delivering 120 VAC, 1 phase.

Space heat for the cabin is provided by wood and propane. The hot water heater, range, and refrigerator (which can use either propane or electricity) are propane powered. The largest electric loads are a microwave and a toaster. The owners occupy this cabin at least two weekends per month all year round and more in the summer.

*Figure 3. Southwest Windpower 503 adjacent to South Park mountain cabin with PV panels on roof, Case Study 3.*

In 1986 when this cabin was built, the electric grid was 3.5 miles (6.5 km) away. Grid extension was not an option. (Recent grid extensions in this area have cost $20,000/mile [$12,430/km].) Preferring not to use an engine-generator, the owners installed the PV panels, batteries, and inverter to provide electric power. A two-bladed wind turbine, a Southwest Windpower 502, was added in July 1992 and the battery bank was doubled in size. This addition provided both more energy and a seasonal compliment to the solar power. Following some bearing problems in 1996, Southwest Windpower replaced this unit with a three-bladed 503 model which has performed flawlessly to date. The wind turbine is on a 32 ft (9.8 m) guyed lattice tower.

The power system installation was done through a combination of owner and professional labor. A building permit was not required for the existing installation because the height is under 35 ft (10.7 m). A permit, with zoning review, would be required to increase the tower height. Normal homeowners insurance is carried on the cabin with no additional premium due to the power system. Noise has not been a problem—turbine noise created during high winds does not exceed the ambient wind noise levels.

A unique feature of this site is that meteorological data—wind speed, air temperature, and solar irradiance—are being recorded continuously and posted on the Internet. The Web site is http://srrl.nrel.gov/spmd.

## Case Study 4

This case study is the home of an "empty nest" couple in rural Douglas County just .5 mile (0.8 km) from Case Study 1. (See Figure 4.) This home has three distinct power systems: an on-grid electric system, an off-grid electric system, and a water-pumping system. The electrical circuits in the home are split into high- and low-voltage systems with a manual transfer switch in between. The 240 VAC circuits are on-grid and serve an electric range, a clothes drier, and an electric welder. The 120 VAC circuits are normally off-grid and are served by a wind-electric system consisting of

- A pair of Winco wind turbines, 450 W, 8 ft (2.4 m) diameter rotor, battery-charging
- 12 VDC battery bank
- Heart inverter delivering 120 VAC, 1 phase.

The manual transfer switch allows the 120 VAC circuits to be grid-connected as backup to the wind system. The water-pumping system consists of a windmill delivering water to a head tank which supplies potable water to the home:

- Aermotor mechanical water-pumping windmill, 8 ft (2.4 m) wheel.

A grid-powered submersible pump in the same well serves as backup. Space heat and hot water are from propane.

*Figure 4. Aermotor windmill and Winco wind turbine adjacent to Douglas County home, Case Study 4.*

All three of the wind machines were installed in the early 1980s with the benefit of the renewable energy income tax credits. Although the wind turbines and windmill are located within 100 ft (30 m) of the house, noise has not been a problem. The owners report a bit of noise in high wind. Wind turbine noise is likely reduced by the turbine design that uses air brakes rather than furling for overspeed control in high winds. It appeared that both the wind turbines and the windmill may now be partially obstructed by trees that have grown up nearby in the years since the machines were first installed. One of the two wind turbines was out of service following a failure in the overspeed governing mechanism. The owner had purchased a new blade and made other replacement parts himself in preparation for putting that turbine back in service. A recent storm, with winds estimated at 90 mph (40 m/s), damaged several blades on the windmill.

This case study is a fascinating snapshot of wind energy history—a juxtaposition of three generations of wind technology. There was the venerable windmill, using a rotor design over 110 years old, next to a pair of small wind turbines of a design first manufactured in the 1930s, all located just .5 mile (0.8 km) down the road from a pair of 1990s small wind turbines (Case Study 1).

The local electric co-op was quoting $10,000 for grid interconnection when power lines were first being installed in the area, and the price went up to $20,000 a couple of years later. The wind systems were installed out of a need for a lower cost alternative to grid-connection and an interest in wind energy. Eventually, the home was connected to the co-op for no charge whatsoever! The minimum billing from the co-op is $25/mo which is about equivalent to the energy consumption by the 240 VAC appliances.

The end result is that this homeowner keeps his electric bills at the minimum while having the confidence of grid backup for the wind energy systems. The homeowner did obtain building permits for the wind systems, and he did the installations himself. The couple carries homeowners insurance but no special coverage for their wind machines.

## Energy Crisis Pioneers

These two case studies are “Energy Crisis Pioneers.” They are wind energy veterans who have lived comfortably with wind energy for well over a decade. Economics were a driver in their decision-making. Specifically, renewable energy was less expensive than grid-connection. And, the financial incentive of renewable energy tax credits was a factor in Case Study 4.

## Case Study 5

This case study is a family of four living in suburban Jefferson County, on the west side of Denver. (See Figure 5.) Their home is near the summit of a hill elevated well above most of the metro area and located about 4 miles (6.4 km) east of the foothills of the Rockies.

*Figure 5. WhirlWind 4000 wind turbine behind home with solar hot-water panels, Jefferson County Colorado, Case Study 5.*

The home is on-grid as is their wind turbine:

- Whirlwind 4000 wind turbine, 4 kW, 16 ft (4.9 m) diameter rotor, grid-connected
- Acheval inverter, 240 VAC, 1 phase.

The major electric appliances include stove, oven, swamp cooler, and a circulating pump for a swimming pool that operates on a clock about 6 hours/day. Space heat and hot water are gas-fired which is supplemented by a solar hot water system. The clothes drier and a swimming pool heater are also gas-fired.

The Whirlwind turbine is from the mid-80s. The Whirlwind company is no longer in business, one of many small companies that did not survive the end of the tax credits. The turbine is mounted on a 100 ft (30 m) guyed tubular tower. The family has owned this home for almost three years but has not operated the wind turbine during that time. The previous owner informed them that it needed servicing and left them an owners manual. They have received only favorable comments from the neighbors about the wind turbine.

This family's main concern was getting information. Initially, they wanted to know who they might sell the turbine to, or who they could give the turbine to as a charitable contribution. In time, they also inquired about other factors including an estimate of the annual wind energy production; information on the net metering tariff available from their utility, Public Service Company of Colorado; and contact information for service/maintenance providers. I note that they have refurbished the solar hot water system including replacing the flat-plate collectors—not a trivial expense.

## Case Study 6

This wind turbine application is at a family home in a dense suburban neighborhood in Lakewood, Colorado, just west of Denver. (See Figure 6.) There are homes and trees surrounding the house on three sides. On the fourth side and just one house away is the 6th Avenue freeway. There is a wind turbine installed in the narrow backyard, an

- Enertech 1800, 13 ft (4 m) diameter rotor, 1.8 kW rated power, grid-connected.

This machine has an induction generator and operates directly connected to the grid without batteries. The turbine is 65 ft (20 m) high on a self-supported, tubular tower. In addition to the wind turbine, there is also a large solar hot water system on the house supplementing the gas-fired space heat and hot water.

The wind turbine is not currently used. When the present owners purchased the house, they were told that the gearbox oil needed to be changed and the blades needed to be refurbished or replaced. They did operate the turbine briefly and found that the rotor was severely out of balance. Currently, pigeons can be seen nesting inside the unit. The neighbors tell the story that there had been a vigorous zoning debate prior to the wind turbine installation with noise being the primary concern. Although a building permit was eventually granted, current zoning laws in Lakewood prohibit new installations like this one. It is ironic that noise was a concern since traffic noise from the adjacent freeway is dominant in this neighborhood.


*Figure 6. Enertech 1800 wind turbine from across the 6th Avenue freeway, Lakewood, Colorado, Case Study 6.*

As with the previous case study, the primary need of this family was access to information. Who can overhaul the wind turbine and what will it cost? How long will the tower be structurally sound? What about net metering with the utility? They did not even receive an owners manual for the turbine when they bought the house.

## Second Owners without a Clue

These last two case studies are "Second Owners without a Clue." They are normal, intelligent people who didn't go looking for wind energy—it found them! They bought a house from one of the "Pioneers" and there was a nonfunctional wind turbine in the back yard along with a nonfunctional solar hot-water system on the roof. Very simply, they don't know what to do with their wind turbines. They are not familiar with wind energy, they don't know what value the turbine could have, or who to call to get it serviced. Because their wind turbines are not currently functional, the two assets with the highest value are the towers and the zoning for those towers. Many of the early 1980s wind turbines are better suited for do-it-yourself owners who are willing to climb towers and able to provide lots of tender loving care.

## What Did I Find?

In the course of these case studies, I found a number of interesting things. One of my favorites was the three generations of wind technology. From windmills to the 1930s wind-chargers to the new small wind turbines of the 80s and 90s—this is time-tested technology. At the same time, I also found mechanical failures in all three generations. At first glance these are contradictory findings. For perspective, we must bear in mind that wind turbines are machines like household appliance and automobiles. They require routine maintenance and, at times, repair. Consider that a small wind turbine may be spinning more hours in <u>one</u> <u>year</u> than a car driven 200,000 miles (320,000 km)!

With nearly every case study, I found problems with turbine siting. By "siting," I mean choosing the location and height of the wind turbine to ensure access to strong, smooth winds. Obstacles such as trees and houses on adjacent properties were common. They reduce the wind speed and add turbulence which reduces both wind turbine performance and life. Trees on the turbine owner's properties were also common—trees that have grown since the original turbine installation. And, there was a site with turbulence created by the steep up-slope of a hill. Every wind turbine I saw could have benefited from being on a taller tower.

All of the wind turbine owners were matter-of-fact about living with wind turbine noise. It may help that the wind turbines sound like kWhs to them. It also true that there are relatively few hours per year when the winds are high enough to furl the wind turbines—the noisiest operating mode. And on those occasions, the ambient wind noise is also high and people tend to be indoors with the windows shut.

I found a wide variety of power systems. There were on- and off-grid systems, and systems split into high and low voltages each served from a different source. The three newest systems were hybrids of wind and PV. Because solar and wind resources are complimentary, the hybrid of the two is more cost-effective and a better performer than a single-source renewable power system. A bit surprising, I found all-electric homes powered by renewable energy. I also found wind machines serving a variety of electric loads: battery-charging, grid-connection, and mechanical water-pumping.

I did find evidence of regulatory obstacles to wind energy. One of the new systems does not yet have approval from the state electric inspector due to lack of a UL label on the wind turbine controller. The same system is the subject of a costly and time-consuming zoning review about tower height. I learned that zoning review may not be required for very short towers, under 30 to 35 ft (9.1 to 10.7 m).

I found that these case studies, in hindsight, were not overly instructive about the current economics of wind energy. The four older applications—the Pioneers and the Second Owners—reflect installation costs from the 1980s. And, the cost data were incomplete in any case. The Zealots have recent installations, but not "least-cost" installations. These factors and a desire to respect the privacy of the homeowners resulted in cost data not being included in these paper.

Overall, I found great variety in these case studies. In fact, diversity of the applications seems to be a defining characteristic of small wind energy technology. The people using wind energy—the Zealots, the Pioneers, and the Second Owners—are no less diverse.

## What's Needed?

As I conclude, I remind myself and the reader that these case studies are not a comprehensive survey. They can't be used to make any quantitative assessments about small wind energy in Colorado. But, they do illuminate several important factors that could contribute to a stronger marketplace and more successful utilization of small wind turbines. I close with the following list of needs/issues for small wind turbine applications. For the most part, these are things I did <u>not</u> find in my case studies.

- **Taller Towers—**Higher is better. It will result in wind turbines that are more productive, more reliable, and have longer useful lives. Going higher will always have to be balanced against the incremental cost of the taller tower, possible increased resistance to zoning approval, and some increased difficulty in climbing the tower to do maintenance.
- **Zoning—**There is a need for zoning rules that are fair to both the turbine owners and to their neighbors. Zoning reviews need to be reasonable in terms of cost and time. For instance, the $400 zoning fee from Case Study 2 is nearly equal to the purchase price of one of today's best-selling small wind turbines. Effecting nationwide change in zoning rules is an immense challenge due to the large number of counties and municipalities. Mandating change through state legislation might be the only practical approach.
- **Education and Technical Assistance—**The need for information about wind energy is the most basic need of the Second Owners. Very likely, prospective wind turbine buyers would also benefit from knowledgeable, objective, and local technical assistance, if it were available. I encourage local renewable energy associations, such as the Colorado Renewable Energy Society, to provide such assistance to the public through a volunteer program by their members.
- **UL Labels—**The wind industry needs to invest in third party safety evaluations of their electrical components. The requirement for such review has statutory authority in Colorado and probably in many other states. The challenge here is that the evaluations will be a significant financial burden to the small companies that make up the industry. Financial assistance for this purpose could accelerate the industry transition to labeling as routine business practice.
- **NEC Compliance—**With some small wind turbines being installed by the owners themselves, NEC (National Electric Code) compliance is mixed. Like safety evaluations, compliance with the NEC has statutory authority in Colorado and probably in many other states. A handbook that interprets the code for small wind turbine applications would be valuable to both the do-it-yourselfers and professionals.
- **Wind Turbine Certification—**Third-party evaluation of performance, safety, and reliability would allow new users to enter the market with increased confidence. The evaluation process itself will also improve the products brought to market.

  (Note: The previous three items would all help make small wind systems both insurable and financeable. Neither insurance or finance were factors in my case studies, but they would be in a more mature market in which small wind turbines are more like a consumer product.)
- **Net Metering—**Net metering is a valuable incentive for on-grid wind turbine owners. The market for small wind power would benefit if net metering tariffs were universally available and better publicized. Currently 30 states have net metering to some extent, but <u>only 19 states</u> have rules ensuring that net metering for wind energy is available to all rural residents—the people most likely

to be able to use wind energy. I'm partial to net metering programs without capacity limits, and with any excess power credited to the following month and given to the host utility's low income assistance program at the end of each year.

- **Rebates/Buy-Downs/Tax Credits—**The current economic realities are that financial incentives are needed for home-scale renewable power systems to compete with grid power. Incentives will be necessary if the market is to attract customers beyond the Renewable Zealots. Off-grid systems, usually competitive already, would be all the more attractive. I note that a production-based incentive might be preferred to a capacity-based incentive. Currently, no such incentives are being proposed for small wind turbines. The capacity-based incentive of the 1980s, the renewable energy tax credit, resulted in the installation of lots of poor quality wind turbines.
- **"Plug & Play" Packaged Systems—**Vendors that package renewable power systems would take the burden of system design and integration off the shoulders of consumers. While the Renewable Zealots relish this task, the general public does not.
- **Small Wind Turbine Service Industry—**Local expertise in wind power is hard to find. Of course, there is a "Catch 22." With few wind turbines, a service industry can't emerge, but without service providers, wind turbines are less attractive to the consumer. Another factor is that many wind turbine owners choose to install and maintain their wind turbines themselves to keep costs down.
- **Wind Resource Assessment—**Detailed wind resource maps at the state level are lacking for most states. This makes it difficult to estimate wind speeds for specific locations and measuring the wind resource is expensive relative to the cost of the wind turbines.
- **Small Wind Turbine for Grid-Connection**—In the 1980s, there were numerous small wind turbines designed specifically for direct grid-connection. That is no longer the case. The products currently on the market are mostly battery-charging wind turbines. These turbines certainly can and are being grid-connected, but require the added expense of battery banks. In the current market, there are only two wind turbine models designed for direct grid-connection with the smallest being 10 kW in size.

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